High speed, multi-channel, thermal instrument development in support of HyspIRI-TIR

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ABSTRACT

The Jet Propulsion Laboratory is currently developing an end-to-end instrument which will provide a proof of concept prototype vehicle for a high data rate, multi-channel, thermal instrument in support of the Hyperspectral Infrared Imager (HyspIRI)–Thermal Infrared (TIR) space mission. HyspIRI mission was recommended by the National Research Council Decadal Survey (DS). The HyspIRI mission includes a visible shortwave infrared (SWIR) pushboom spectrometer and a multispectral whiskbroom thermal infrared (TIR) imager. The prototype testbed instrument addressed in this effort will only support the TIR. Data from the HyspIRI mission will be used to address key science questions related to the Solid Earth and Carbon Cycle and Ecosystems focus areas of the NASA Science Mission Directorate. Current designs for the HyspIRI-TIR space borne imager utilize eight spectral bands delineated with filters. The system will have 60m ground resolution, 200mK NEDT, 0.5C absolute temperature resolution with a 5-day repeat from LEO orbit. The prototype instrument will use mercury cadmium telluride (MCT) technology at the focal plane array in time delay integration mode. A custom read out integrated circuit (ROIC) will provide the high speed readout hence high data rates needed for the 5 day repeat. The current HyspIRI requirements dictate a ground knowledge measurement of 30m, so the prototype instrument will tackle this problem with a newly developed interferometeric metrology system. This will provide an absolute measurement of the scanning mirror to an order of magnitude better than conventional optical encoders. This will minimize the reliance on ground control points hence minimizing post-processing (e.g. geo-rectification computations).

Keywords: imaging, spectroscopy, Multi-spectral, MCT, thermal, LWIR

1. INTRODUCTION

The National Research Council (NRC) Decadal Survey recently recommended 14 missions for implementation by NASA [1]. One of the missions identified is called HyspIRI. It consists of a Visible ShortWave InfraRed (VSWIR) imaging spectrometer, and a Thermal InfraRed (TIR) imaging multispectral scanner. Both of the HyspIRI instruments will be used to address key science questions related to the Carbon Cycle and Ecosystems, Climate, and Solid Earth focus areas of the NASA Science Mission Directorate. The technology for the HyspIRI-TIR instrument is mature but further work is needed to reduce risk. In particular, the proposed design requires a high sensitivity and high throughput Focal Plane Array (FPA), combined with a scanning mechanism that requires stringent pointing knowledge. The scanning approach, and the high sensitivity and high throughput FPA, are required to meet the revisit time (5 days), the high spatial resolution (60m), and the number of spectral channels (8) specified by the Decadal Survey, and the HyspIRI Science Study Group for the mission [2]. The next step is to reduce the risk associated with the scanning mechanism and the FPA with the development of a laboratory prototype termed the Prototype HyspIRI Thermal Infrared Radiometer (PHyTIR). PHyTIR will demonstrate that:

- The detectors and readouts meet all signal-to-noise and speed specifications.

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- The scan mirror, together with the structural stability, meets the pointing knowledge requirements.
- The long-wavelength channels do not saturate below 480 K.
- The cold shielding allows the use of ambient temperature optics on the HyspIRI-TIR instrument without impacting instrument performance.

The long wave infrared (LWIR) is typically expressed as the wavelength range between 7 and 14 μm. The HyspIRI mission includes a visible shortwave infrared (SWIR) spectrometer and a multispectral thermal infrared (TIR) imager. Data from the HyspIRI mission will be used to address key science questions related to the Solid Earth and Carbon Cycle and Ecosystems focus areas of the NASA Science Mission Directorate. More specifically, the LWIR component of the HyspIRI mission will address science questions in five main science themes:

Volcanoes
What are the changes in the behavior of active volcanoes? Can we quantify the amount of material released into the atmosphere by volcanoes and estimate its impact on Earth's climate? How can we help predict and mitigate volcanic hazards?

Wildfires
What is the impact of global biomass burning on the terrestrial biosphere and atmosphere, and how is this impact changing over time?

Water Use and Availability
As global freshwater supplies become increasingly limited, how can we better characterize trends in local and regional water use and moisture availability to help conserve this critical resource?

Urbanization
How does urbanization affect the local, regional and global environment? Can we characterize this effect to help mitigate its impact on human health and welfare?

Land surface composition and change
What is the composition and temperature of the exposed surface of the Earth? How do these factors change over time and affect land use and habitability?

2. System Overview

The PHyTIR system will be a complete end-to-end laboratory system. The system will utilize an existing Read-Out Integrated Circuit (ROIC) that has been developed as part of the HyspIRI Concept Study. The ROIC will be mated with the detectors and filters, all located inside PHyTIR. The scanning mechanism will operate at the same speed as the HyspIRI-TIR instrument and have the same pointing knowledge requirements.

Figure 1a shows the HyspIRI-TIR instrument concept while figure 1b shows a graphical representation of the scanning approach. The instrument utilizes a rotating scan mirror to allow the telescope to view a 51° cross-track nadir strip, an internal blackbody target, and Space, every 2.1 seconds with a nadir resolution of 60m.

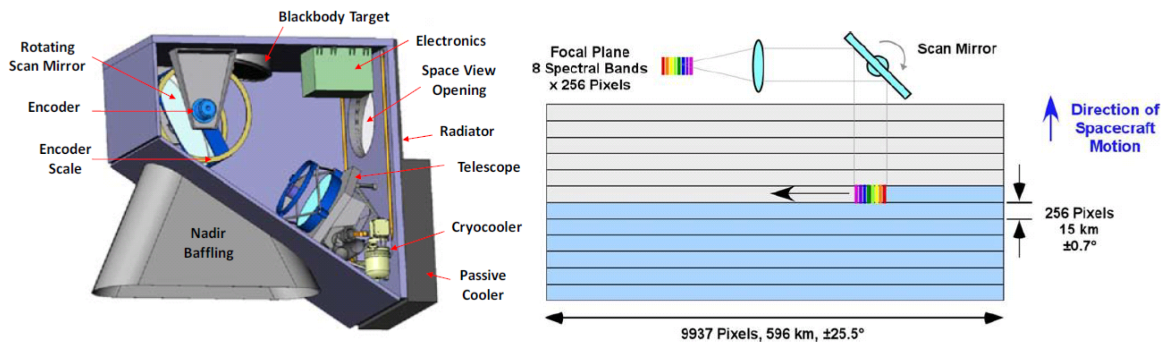

Figure 1. a) HyspIRI Instrument Concept, b) HyspIRI scan method

A detailed set of instrument characteristics is provided in Table 1. The 5-day revisit requirement necessitates a wide swath, which is realized by the scan method illustrated in Figure 1a. The scan mirror sweeps the image of the focal plane across a 51° swath perpendicular to the spacecraft motion. Each point in this strip is sampled by detectors in all 8 spectral channels. The sweep rate is such that, as the spacecraft moves, the full 51° swath is sampled, with a small overlap between strips. The relatively fast sweep rate requires a fast frame-rate focal plane.

Table 1. Detailed set of instrument characteristics

HyspIRI TIR Instrument Characteristics			
Spectral		**Spatial**	
Bands (8)	3.98 µm, 7.35 µm, 8.28 µm, 8.63 µm, 9.07 µm, 10.53 µm, 11.33 µm, 12.05 µm	IFOV	100 µrad; 60 m at nadir
Bandwidths	0.084 µm, 0.32 µm, 0.34 µm, 0.35 µm, 0.36 µm, 0.54 µm, 0.54 µm, 0.52 µm	MTF	>0.60 at FNy
Accuracy	<0.01 µm	Scan Type	Push-Whisk, 14.2 RPM mirror rotation
Radiometric		Cross-Whisk Samples	256
Temperature Range	Channel 1: 400-1200 K Channel 2–8: 200 K – 480 K	Samples in Whisk Direction (Cross Track)	9,300
Resolution	< 0.05 K, linear quantization to 14 bits	Cross-Whisk Swath Width	15.4 km (±0.7° at 623 km altitude)
Accuracy	< 0.5 K at 250 K	Swath Length in Whisk Direction	596 km (±25.5° at 623 km altitude)
Precision (NETD)	< 0.2 K	Band to Band Co-Registration	0.2 pixels (12 m)
Linearity	>99% characterized to 0.1 %	Pointing Knowledge	10 arcsec (0.5 pixels, 30 m)

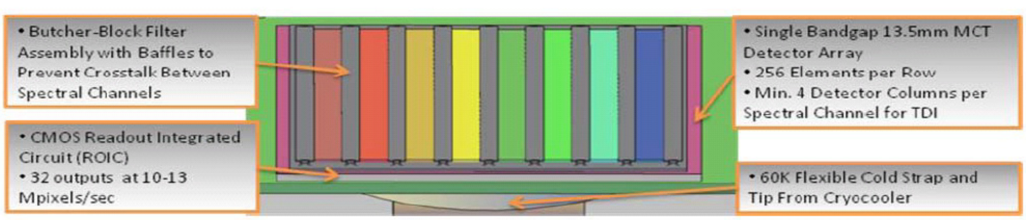

Figure 2. Butcher-block filter layout on top of focal plane.

All eight spectral channels are measured with a single cooled bandgap Mercury Cadmium Telluride (MCT) detector array. Thirty two output signals at 10-13 Mpixels/sec enable the data to be read from the array for the 596 km swath with 60 m nadir resolution. Spectral separation is achieved using filters placed in close proximity to the detector array. Under each filter are 16 columns of 256 pixels. The signals from four of these columns will be read out and averaged using time-delay integration (TDI) to double the signal-to-noise ratio compared to a single pixel column. The columns of 256 pixels are aligned perpendicularly to the cross-track sweep direction (Figure 2). The four columns of 256 pixels are read out in each of the eight spectral channels every 32 microseconds, resulting in a total data rate of 256 Mpixels/sec. Figure 3 shows the NEΔT of the HyspIRI-TIR channels.

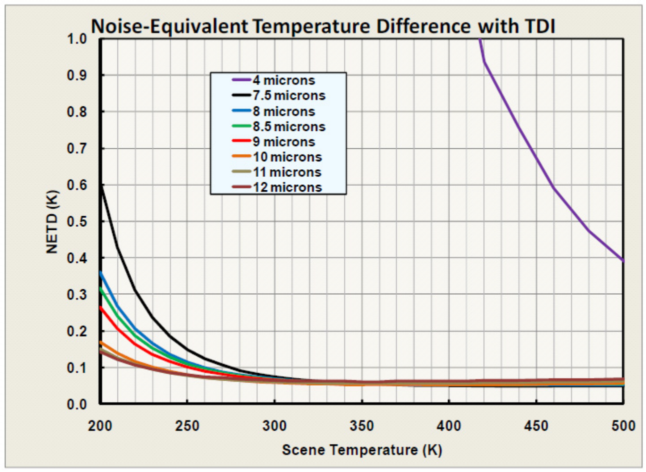

Figure 3. Noise Equivalent Delta Temperature Characteristics of the HyspIRI-TIR Channels.

There are 7 spectral channels between 7 and 12 µm and 1 spectral channel at 4 µm. The specification for the NEΔT of the 7 channels between 7-12 µm channels is better than 0.2K at 250K. The 4 µm band is included specifically for hot targets and has saturation temperature of 1200K. The thermal infrared channels have saturation temperatures of 480K. Although the focal plane and focal-plane baffle are cooled to 60 K, the telescope remains at ambient temperature. Careful optical design is needed to ensure that radiation from the telescope assembly does not degrade the instrument performance.

SUMMARY OF UNDERTAKING AND FINAL TESTING

The following steps are currently being undertaken to build PHyTIR: 1) Design and Build the Scan Mechanism, 2) Design and Build a Scan Mirror, 3) Integrate the Spectral Filters with Focal Plane Array and ROIC, 4) Assemble the Dewar with external telescope, internal relay and focal plane assembly, 5) Build the prototype Electronics and 6) Assemble PHyTIR. Once PHyTIR is assembled it will be used to retire the four key risks as noted earlier. A key part of this effort is the final testing to prove these four key risks so the following four paragraphs describe how each of the key objectives listed above will be tested.

Detectors and readout meet all signal-to-noise and speed specifications. Measurements of the two blackbodies, one at 300K and one at elevated temperature, while the scan mirror rotates, will allow measurements of the response of the detectors to a known signal. The measured detector noise during this test will be combined with the measured responsivity to provide instrument sensitivity. This test will be performed at the HyspIRI focal-plane readout rate, confirming the focal-plane readout speed.

Scan mirror and structure meet pointing knowledge requirements. The ability to achieve 30 m geolocation with the HyspIRI TIR instrument will depend largely on the mechanical scan rate accuracy, the stability of the instrument structure, and accurate time stamping of the scan mirror encoder and focal-plane signals. This capability will be tested using the target projector as a source. The ability of the prototype to reproducibly record the scan angle as each detector is illuminated by the slit will be tested. Furthermore, thermal stability experiments will be conducted by electrically heating different parts of the optical bench while imaging the target projector slit. These tests will be conducted at a range of field angles to ensure precise pointing over the full 51° nadir swath.

Long-wavelength channels will not saturate below 480 K. The variable temperature blackbody temperature will be increased to 500 K while the prototype instrument is scanning to determine the saturation temperature of the long-wavelength channels. This test will also determine the response of the 4 μm channel in the cross-over temperature range where all channels are responsive.

Background from ambient temperature optics does not affect instrument performance. The focal-plane signals will be measured over a blackbody temperature range of 300-500 K. These measurements will allow extrapolating of the focal-plane signals to cold scenes to determine the approximate background contribution from the optical system. Knowledge of this background contribution will allow calculation of background photon shot noise as well as whether background photons fill the detector wells significantly. Additionally, electrical heat will be applied to different parts of the optical bench to determine if temperature changes induce any background drifts that cannot be removed by the frequent looks at the reference blackbody.

BENEFITS TO THE EARTH SCIENCE COMMUNITY

This activity will benefit the development of any airborne or spaceborne system that will utilize a high speed scanning mirror coupled with a MCT detector array to obtain a wide swath width, high spatial resolution, thermal infrared measurement with an NEΔT of approximately 0.2K. Similar systems [3] have been used in the Moderate Resolution Imaging Spectroradiometer (MODIS), Visible Infrared Imaging Radiometer Suite (VIIRS), Advanced Spaceborne Thermal Emission Radiometer (ASTER) and Landsat (TM5/ETM+) instruments. However, none of these existing systems has sufficient performance to meet the measurement requirements of the HyspIRI-TIR instrument [4,5]. PHyTIR will demonstrate that HyspIRI-TIR required high accuracy measurements can be made and help enable both the HyspIRI-TIR instrument as well as other future instruments built by Governments or Commercial Companies that utilize similar technology.

ACKNOWLEDGEMENTS

This research was carried out at the Jet Propulsion Laboratory, California Institute of Technology, under a contract with the National Aeronautics and Space Administration. Reference herein to any specific commercial product, process, or service by trade name, trademark, manufacturer, or otherwise, does not constitute or imply its endorsement by the United States Government or the Jet Propulsion Laboratory, California Institute of Technology.

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